THE RESULTS OF DYNAMIC DATA ACQUISITION DURING MARS PATHFINDER PROTOTYPE AIRBAG DROP TESTING

Gregory L. Davis
Dynamics Environments Group
Mechanical Systems Engineering and Research Division
California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109

ABSTRACT

The Mars Pathfinder mission, scheduled for launch in December, 1996, will use an airbag system to safely deliver a lander to the Martian surface. The airbag landing system has undergone a comprehensive test program during its evolution from initial design phase to final qualification and acceptance testing. This system was extensively instrumented during the prototype drop test program at NASA Lewis Research Center's Plum Brook Station to provide data on airbag performance and kinematical motion of the lander. Test and analysis objectives for this test series included measuring lander accelerations, airbag tendon forces, and airbag pressures and temperatures. This paper outlines the test approach used in the airbag development program, describes the data acquisition system used to obtain and evaluate airbag performance data, and presents test results.

INTRODUCTION

The Mars Pathfinder mission is part of the Discovery Program, a National Aeronautics and Space Administration (NASA) initiative for a new class of smaller missions utilizing the "faster, better, cheaper" approach to planetary exploration. Its principal mission objective is to demonstrate a simple, reliable, and low-cost system for placing a scientific payload on the surface of Mars. Pathfinder is currently scheduled to be launched from a Delta II launch vehicle in December 1996, and after an eight month cruise land on Mars in July 1997. Planned Pathfinder activities on Mars include acquisition of surface images; deployment of a microrover; and scientific investigations of the Martian atmosphere, meteorology, and surface elemental composition. The lander portion of the spacecraft in the deployed surface configuration is depicted Figure 1.

Pathfinder also represents the first landing mission to Mars since the Viking missions of two decades ago. Unlike Viking, Pathfinder will not soft land using a rocket system to brake its descent, but rather will use an airbag system to safely deliver the lander to the Martian surface. The entry/descent/landing (EDL) sequence for the Pathfinder mission is depicted in Figure 2. This paper outlines the test approach used in the airbag development program, describes the data acquisition system used to obtain and evaluate airbag performance data, and presents test results.

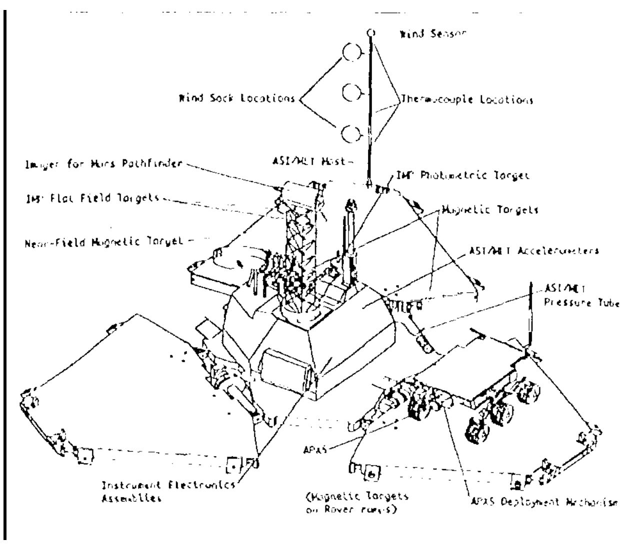

Figure 1-Mars Pathfinder in the Landed Configuration

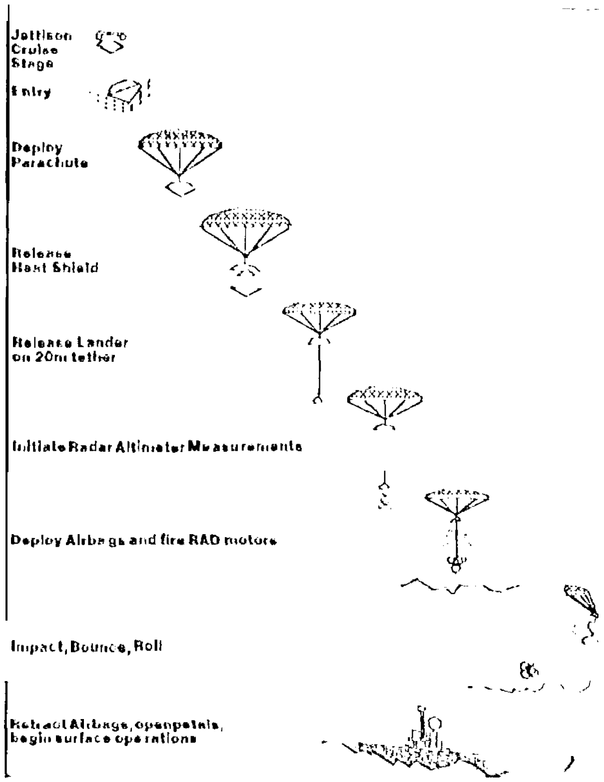

Figure 2-Pathfinder Entry Descent Landing Sequence

AIRBAG DROP TEST PROGRAM

Background

The Mars Pathfinder airbag landing system has undergone a comprehensive test program during its evolution from initial design phase to final qualification/acceptance testing of the flight airbag landing system. The Jet Propulsion Laboratory (JPL) and Sandia National Laboratory began a collaboration in 1993 to design, fabricate, and test a scale model airbag landing system as a proof of concept demonstration for the Mars Pathfinder spacecraft.

The first series of tests, performed in May 1993 in the Sandia High Altitude Chamber (HAC), consisted of a stationary .38 scale model airbag landing system struck by an accelerating impact plate. The mass of the impact plate and airbag pressures were appropriately scaled to preserve the integrity of the simulation for ambient Martian landing conditions. Eighteen impact tests were conducted with variations in impact velocity and airbag orifice areas. Subsequently, a supplementary series of tests was conducted at Sandia's Coyote Canyon Test Facility to assess the structural integrity of the airbag landing system.

A second series of tests was performed in September 1994 at the Sandia HAC under nearly identical test conditions. The objectives of this series of tests were to evaluate the performance of the second generation airbag design and validate the predictions made by the underlying mathematical model of the airbag landing system. Of particular interest was the effect of orifice size on airbag performance. Fifteen impact tests were conducted with variations in impact velocity and airbag orifice areas.

These proof of concept tests are considered to have successfully demonstrated the feasibility of using an airbag landing system for a planetary lander [1]. Buoyed by these test results, JPL let a contract to ILC Dover Inc. to fabricate and demonstration test an airbag landing system for Mars Pathfinder.

Flight System Drop Testing

In collaboration with ILC Dover Inc., JPL began a much more extensive series of drop tests on full scale prototype airbag systems beginning in April 1995. This series of tests had the following objectives for an airbag landing system operating under Martian ambient conditions:

- to measure lander accelerations, airbag tendon forces. and :iil-imp, pressures and temperatures
- to assess the airbag bladder design and fabric abrasion resistance properties
- to determine the frequency and magnitude of the landing excitation
- to use these prototype test results to direct subsequent design modifications

This prototype testing took place at NASA Lewis Research Center's Plum Brook Station in the Space Power Facility (SPF), the world's largest space environmental test chamber.

Based on the results of the JPL/Sandia proof of concept testing, the prototype airbag landing system design consisted of an airbag attached to each face of the tetrahedral lander by means of internal and external tendons, thereby cocooning the lander in a total of 4 airbags. Each triangular shaped airbag has 6 lobes approximately .9 m in diameter- the lobes being separated by approximately 1 m- giving each airbag a total volume of approximately 12.5 m^3. The airbag attached to the bottom of the tetrahedron (or base petal) is vented by means of internal orifices to each of the other airbags to provide a damping mechanism. One of the airbags with its attach tendons is depicted in Figure 3.

The test configuration consisted of the prototype airbag system attached in flight-like fashion to a full scale engineering unit lander. The airbags were instrumented with thermocouples and pressure transducers to measure their thermodynamic performance parameters; additionally, for the prototype 1 drop series, the tendons connecting one of the airbags to the lander were instrumented with strain gages to measure the inline tendon forces. The lander was instrumented with accelerometers to record its kinematic motion; in turn, all of this data was recorded on a portable data acquisition system mounted inside the moving lander. The combined airbag/lander assembly was suspended from the top of the SPF chamber and impacted onto either a horizontal surface or a platform inclined at 60° with a simulated rock field.

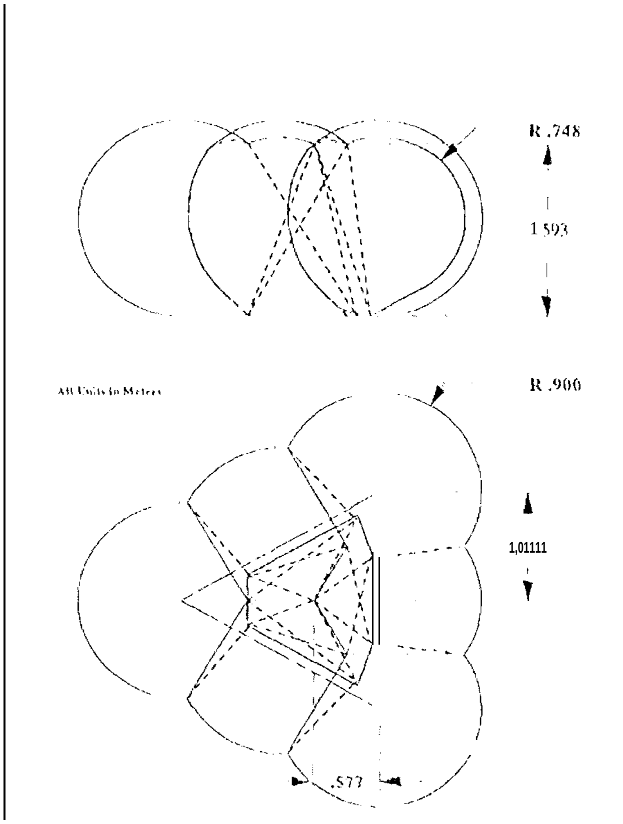

Figure 3 - Six-lobe Airbag Schematic

Figure 4 - Drop Test Setup

For the initial drops, the airbag/lander system ftvc-fell vertically to a horizontal surface without the simulated rock field. For all subsequent drops, the airbag/lander system was impacted vertically onto the inclined platform with the rock field. The 60° inclined platform simulates the design landing condition of 30° with respect to the Martian surface, and the rock field simulates the best estimate of the actual Martian surface rock distribution based 011 Viking lander data. To compensate for the loss of drop height caused by the platform, higher velocity impacts were assisted by bungee cords tied to the bottom of the lander. All drops took place at pressures of approximately 5 torr, Martian surface ambient conditions. The drop test setup with the inclined platform is depicted Figure 4.

Table 1 below summarizes the flight system testing of the airbag landing system under various test conditions. These prototype development tests have successfully led to an optimized design for the flight airbag landing system to be used on the Mars Pathfinder spacecraft. The final qualification/acceptance testing for flight airbag landing system took place at NASA Lewis Research Center's Plum Brook Station in April 1996.

Table I: Prototype Airbag Drop Test Summary

Prototype 1				
Drop	**Speed (m/s)**	**Rock Size (m)**	**Airbag Pressure (psia)**	**Comments**
1	15.00	0	1.5	vertical only
2	15.00	0	1.5	vertical only
3	20.00	0	1.5	vertical only
4	15.00	.5	1.5	60° platform
5	20.00	.5	1.5	60° platform
Prototype 2	Multiple constructions tested			
Drop	**Speed (m/s)**	**Rock Size (m)**	**Airbag Pressure (psia)**	**Comments**
6	16.00	.5	1.5	60° platform
7	16.00	.5	1.5	60° platform
8	22.85	.3	1.5	60° platform
9	22.85	.3	1.0	60° platform
10	22.30	.3	.92	60° platform
11	22.64	.3	.89	60° platform
12	27.81	.3	.92	60° platform
FSD	(Full Scale Development)		Inflation test followed by drop	
Drop	**Speed (m/s)**	**Rock Size (m)**	**Airbag Pressure (psia)**	**Comments**
FSD1	28.03	.3	.92	60° platform
FSD2	25.40	.3	.94	60° platform
FSD3	23.96	.5	.91	60° platform
Qual	(Qualification)		Inflation test followed by drop	
Qual1	25.75	.5	1.03	60° platform
Qual2	26.15	.5	1.08	60° platform

INSTRUMENTATION AND DATA ACQUISITION

The Mars Pathfinder airbag landing system was extensively instrumented during the prototype drop test program to provide data on airbag performance and kinematical motion of the lander. Test and analysis objectives included measuring lander accelerations, one set of airbag tendon forces, and airbag pressures and temperatures.

Data Acquisition Requirements

Because the Pathfinder lander/airbag system was to be tested under unusual and relatively harsh environmental conditions, standard recording equipment and data acquisition techniques could not be used. Specifically, these test conditions required utilizing a ruggedized, portable data acquisition system able to remotely operate under high g loads and low temperatures in near vacuum conditions. The test and analysis objectives necessitated utilizing a robust, multichannel digital data recorder capable of recording data from a variety of transducer types. The data acquisition system's functional requirements are summarized in Table II.

Table II: Data Acquisition Requirements Summary

Environmental Requirements	
g loads	75 g
operating temperature	-20°C - +40°C
operating pressure	5 - 760 torr
Recording Requirements	
channels	≥ 30 (sample-and-hold required)
min frequency range	0- 200 Hz; anti-alias filter required
dynamic range	≥ 40 dB
record time	≥ 5 s; remote trigger
data	digital output; ASCII format desired
Transducer Requirements	
accelerometers	≥ 6 (1 per DOF); 75 g max
force transducers	16 (1 per A/B tendon); 9 klb max
temperature	4 (1 per A/B); -20°C-+40°C
pressure	4 (1 per A/B); 2.9 psia

Recording System

A survey of dealers in the data acquisition field uncovered only two vendors both from an automotive industry background having products potentially capable of meeting these requirements, After receiving bids from both manufacturers, cognizant test personnel recommended procurement of the SoMat/Robert A. Denton Inc. Intelligent Dummy Data Acquisition System (IDDAS), a system originally designed for anthropomorphic test dummies used in automotive crash testing. This system was selected based on the following technical merits:

- compact size and low power consumption
- high number of channels and large storage capacity
- robust, variable sample rates
- built-in signal conditioning and filtering
- built-in analog to digital conversion
- built-in shunt calibration capability
- user friendly software interface

The IDDAS technical specifications are summarized in Figure 5, and a picture of its installation in **the** lander is given in Figure 6.

IDDAS

SYSTEM SPECIFICATIONS

Number of channels	8	48	--	channels
Transducer excitation	*±2.5	*±5.0	--	volts
Gain range	*1	*2,720	--	--
Input voltage range (Gain= 1)	±2.5	--	±3.0	volts
Digital battery backup life	30	60	45	minutes
Main battery life	1	**	**	hours
Crosstalk between channels	--	-80	--	db
Signal to noise ratio	**70**	--	--	db
Common mode rejection	90	--	--	db
A-to D resolution	12	12	12	bits
Sample rate	7.63	19,230	-	samples/sec
Sample skew between channels	--	--	none	-
Nonlinearity	--	1	0.5	LSB
Analog guard filter -3db frequency	--	--	10	kHz
Stopband of rolloff filter	--	--	-160	db/decade
Passband gain	-0.5	0.15		db
Filter break frequency	1,000	25,000	--	Hz
Attenuation at the corner frequency	-2.75	--	-3.0	db

*Indicates nominal values. Actual values are measured to an accuracy of 0.05% of the nominal value and the measured data is stored in an EEPROM memory device which is an integral part of the system

**Battery life is dependent on the number of active channels

Figure 5 - Data Recorder Specifications

Transducers

To accomplish the objectives of measuring lander accelerations as well as measuring tendon loads and pressures and temperatures of the airbags, the Pathfinder lander/airbag system was instrumented with accelerometers, strain gages, pressure transducers, and thermocouples respectively. The transducer types and technical specifications are summarized in Table III.

Table II : Transducer Summary

Accelerometers: *Endevco Model 7264A-100*	
range	2000 g's FS
sensitivity	.025 mV/V/g
frequency response	DC - 5000 Hz
operating temp	-55°C - 121°C
Force Transducers: *Strainsert Strain Gaged Stud Model AY-950131-IG-A*	
	9000 lbs FS
sensitivity	.00027 mV/V/lb
configuration	350 Ω full-bridge
operating temp	< + 50°
Pressure Transducers: *Sensotech Model A-5-7809-01*	
range	.5 - 3 PSIA
sensitivity	.67 mV/V/PSIA
configuration	350 Ω full-bridge
operating temp	-65°F 250°F
Thermocouples: *Type T 22 gauge*	

Acquisition Parameters

The instrumentation suite described above comprises 38 channels of data: 12 accelerometer channels, 16 strain gage channels, 5 pressure channels (1 redundant measurement), and 5 temperature channels. The robust nature of the IDDAS permitted maximum flexibility with minimal penalty for designing the data acquisition parameters. Because knowledge regarding the magnitude and frequency content of the landing excitation was uncertain prior to testing, very conservative sampling rates were selected to preserve data integrity to relatively high frequencies.

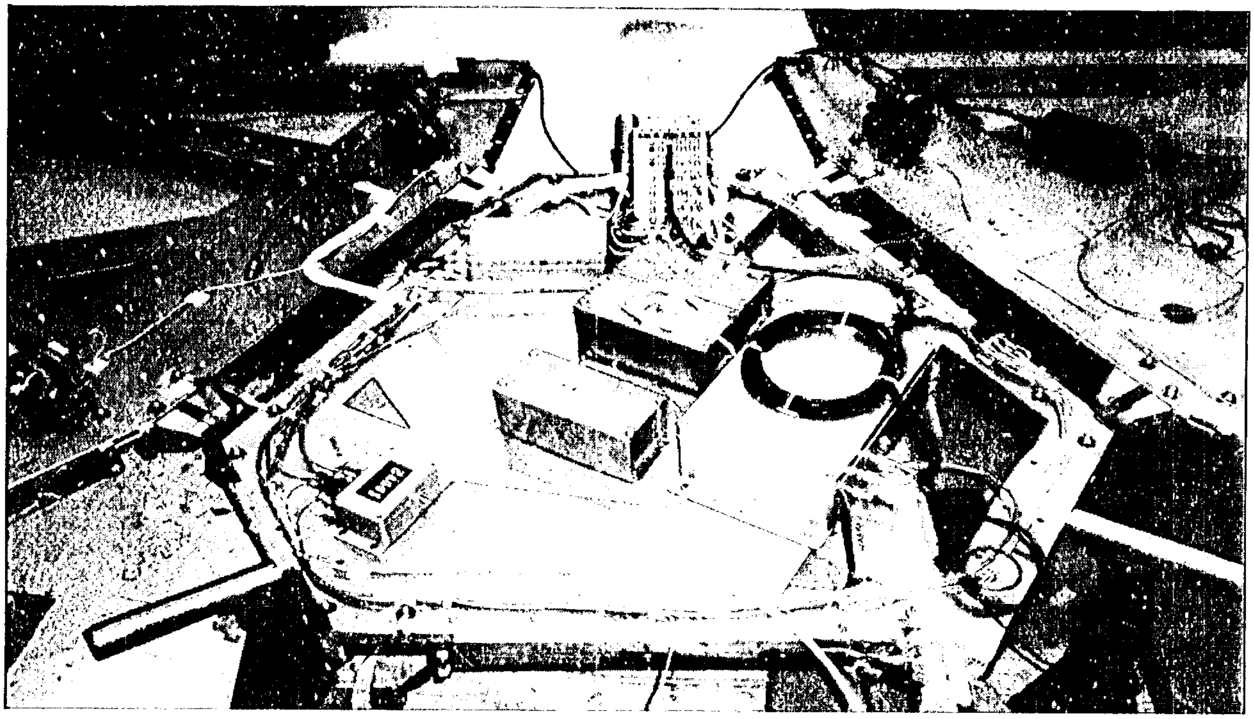

Figure 6 - IDDAS Installed

The IDDAS recorder was configured to sample all data channels at 10000 Hz and antialias filter to 1000 Hz. This still allowed for 26 sec of record time with frequency content up to 1000 Hz for each channel. During the initial drops, conservative full-scale values for each channel were also selected to allow for sufficient "headroom" in the data; these values were then reduced with the later drops. The start of data acquisition and time synchronization with the system clock were initiated with the lander drop signal.

TEST RESULTS

The IDDAS and its complement of transducers successfully met its test objectives by acquiring *full* data sets of lander accelerations, airbag tendon forces, and airbag pressures and temperatures for *all* drops in the prototype test series. Representative time histories from drop 1 for acceleration, force, and pressure data are displayed in Figures 7, 9, and 10 respectively.

Kinematic Analysis

A key objective for this test program was to determine the magnitude and frequency content and of the landing excitation. Toward this end, the lander base petal was instrumented to provide an overdetermined set of triaxial accelerometer readings, thereby making it possible to reconstruct the motion of the lander centroid in all three dimensions using the laws of rigid body kinematics. These acceleration time histories were then numerically integrated using a time stepping algorithm to yield the plots shown in Figure 11 of the trajectory, dispalcement,

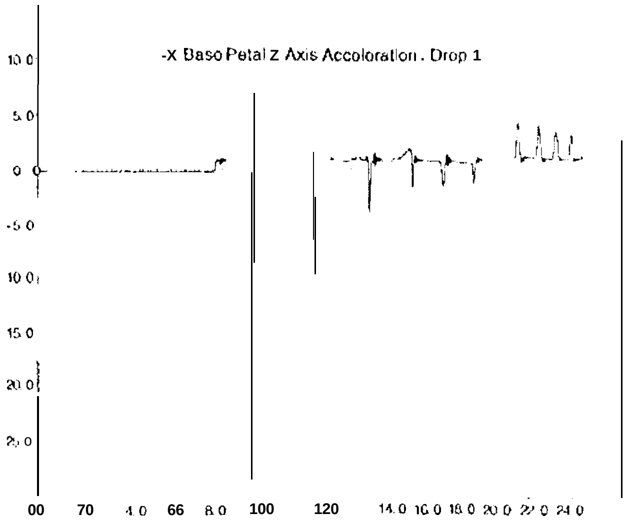

Figure 7 - Lander Vertical Acceleration

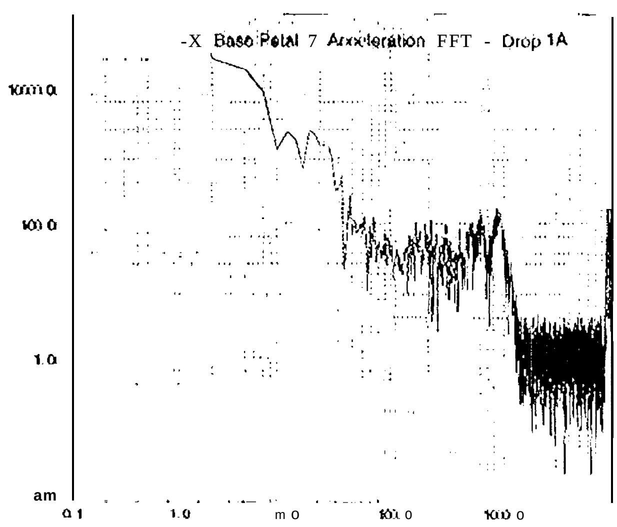

Figure 8 - FFT of Lander Vertical Acceleraton

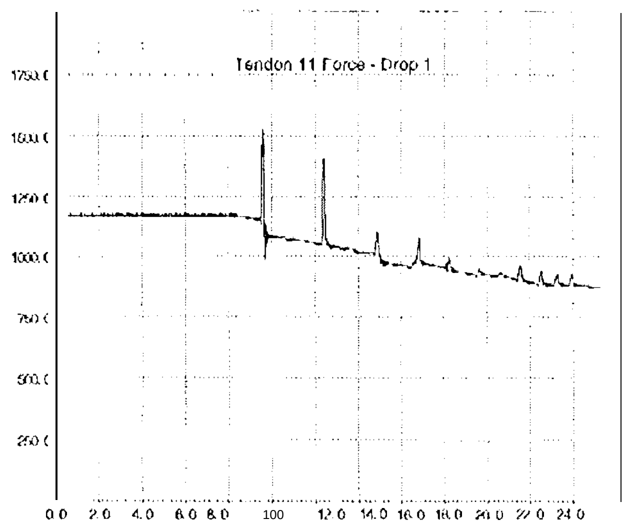

Figure 9 - Airbag Tendon Force

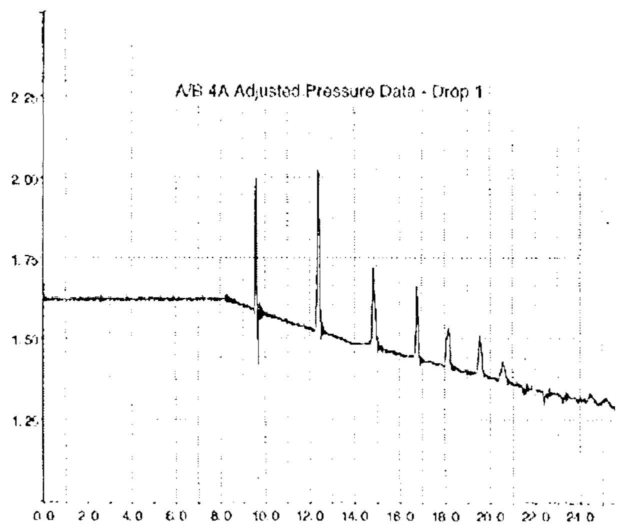

Figure 10 - Airbag Pressure

velocity, acceleration, and angular velocity of the lander centroid in an inertial frame of reference. From this analysis, the resultant landing load derived from a worst-case combination of the translational and rotational components was conservatively bounded at approximately 40 g. The frequency content of the landing excitation was determined from Fourier Transforms of the acceleration time histories, as shown by the representative plot in Figure 8. The predominant energy lobe for this excitation occurs at frequencies below 1 () 117,, implying lander hardware could be tested quasi-statically.

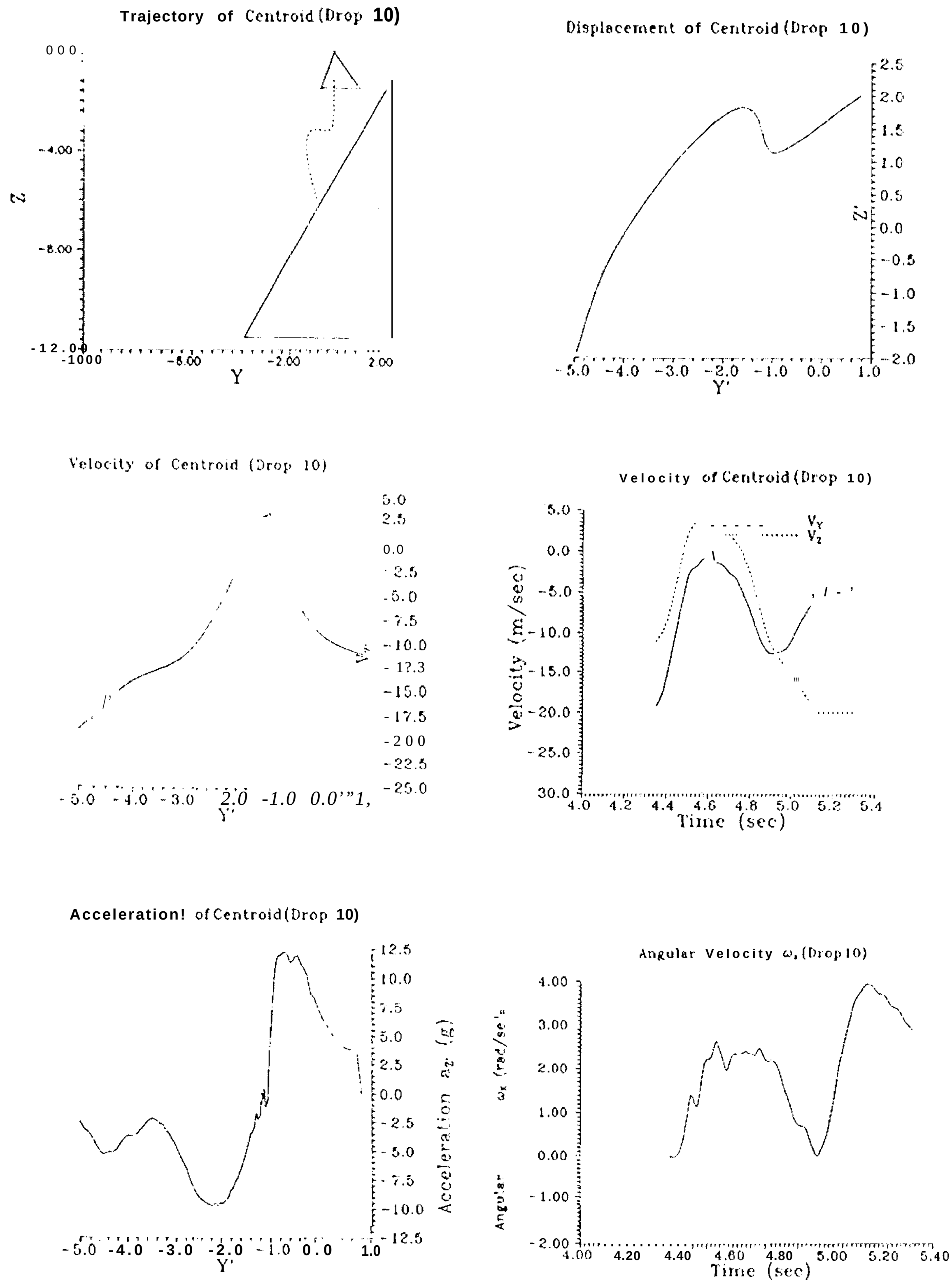

Figure 10 - Results of Lander Kinematic Analysis in an Inertial Frame of Reference

Concluding Remarks

The capability to acquire high fidelity dynamic data for a free-falling test article utilizing a portable data acquisition system able 10 remotely operate under demanding environmental conditions has been demonstrated. The extensive data set provided by this acquisition system during the prototype drop testing, 01' Mars Pathfinder was invaluable in the development and evaluation of the airbag landing system. '1 he force, pressure, and temperature data characterized the performance Of the airbags and its tendon attachments; the acceleration data charecterized the landing excitation as a high g, low frequency event.

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References

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